RADIATION PHYSICS NOTE # 9

A Study of Neutron Attenuation in the E-99 Labyrinth

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INTRODUCTION

We have compared laboratory studies with a Monte Carlo calculation of neutron attenuation in a given labyrinth.

A beam of 300 GeV protons was incident on a thick aluminum block placed between the pole pieces of a standard bending magnet which was at the mouth of a labyrinth. We were concerned with the attenuation of the cascade neutrons that entered the labyrinth after the beam of protons hit the target in the magnet.

A series of TLD dosimeters (both Li^6 and Li^7) was placed in dose equivalent polyethylene moderators along the corridor of the upstream labyrinth in NU Hall on 11/4/73. The responses of these detectors were compared with those predicted by calculations. There was a fairly close agreement between our measurements and the Monte Carlo calculations.

THE EXPERIMENT

A 118 inch long Fermilab external beam bending magnet was installed in the pretarget hall of the Fermilab Neutrino Facility at the mouth of a three-legged labyrinth with two three-feet deep culdesacs. An Aluminum target block was placed 7.88 inches downstream from the face of the magnet. The aperture of the vacuum chamber of the magnet was almost blocked by the target. Figure 1 is a simplified diagram of the geometry. The locations of the TLD detectors are shown also in the figure.

Various types of radiation developed from the target upon impact of the proton beam. Since we were concerned with only the neutrons, we used TLD dosimeters (Li^6 and Li^7) to give us the exposure dose of neutron radiation. These dosimeters were placed in dose equivalent polyethylene moderators. The polyethylene slowed the neutrons down to an energy less than .5ev which is in the thermal neutron range and Li^6 is a good detector of thermal neutrons. We used Li^7 to compensate for the non-neutron component of the dose in Li^6. Li^7 absorbs all radiation except neutrons. We obtained the neutron dose by substracting Li^7's dose from Li^6's dose. Measurements showed that the most of the particles ejected into the labyrinth were neutrons.

The detectors were removed on 11/5/73. They were heated and the photons that came off the detectors were related to the amount of radiation they were exposed to.

Our measurements showed that an exposure of 25,638R of neutrons was directed into the labyrinth. We measured the exposure of the neutrons at each of the detectors which were three feet apart, beginning at the mouth of the labyrinth. We took the readings which can be seen from Table 1. We plotted graphs with these readings on log paper as a function of scaled distance.

We took the exposure readings and normalized them by dividing each reading by the maximum exposure dose of neutrons in the labyrinth. After normalizing the exposure readings, we found that the dose was always falling off as the particles progressed up the labyrinth. Therefore, the maximum of the normalization, which was (1) one, was at the mouth of the labyrinth. We divided each distance the detectors were from the mouth of the labyrinth by the square root of the area of the tunnel. This can be seen from Table 1.

RESULTS

The results of the experiment are shown in Figs. 3 and 4, which compares Zeus's calculated results that we obtained from Fig. 2, to our measured results.

Figure 2 was constructed from Figs. 7 and 8 of the Section "Design of Penetrations in Hadron Shields" by P. Gollon and M. Awschalom in CERN's manual--International Congress on Protection against Accelerator and Space Radiation.

We took Fig. 7 and cut the first leg off at 4.5 units. We then connected the first point of the second leg to the terminal point of the first leg and cut it at 8.5 units. Furthermore, we connected the first point of the third leg in Fig. 8 to the terminal point of the second leg of Fig. 7 at 8.5 units.

We obtained Figs. 3 and 4 by plotting the normalization values against the values of the corresponding scaled distance the detector is from the mouth of the labyrinth. We fitted the points by using parametric functions of the form A/X^2, Be^{-Cx} and $De^{-Fx}/(l+x)^2$ (where l is the distance of the target from the labyrinth mouth). The values of the parameters are shown in Table III. We plotted the line through the triangular points of Fig. 2 on Figs. 3, 4 and 5. (The triangular points represent the points in a labyrinth with culdesacs one unit deep). The data can be read from Table II.

By observation of Fig. 3, the comparison of Zeus's predictions and our measurements in the first leg is bad, in the second leg is better, and in the third leg is good. This is due to Zeus's assumption of a mono-energetic source of neutrons incident in the labyrinth; whereas, we had a spectrum of neutrons incident. The attenuation of the neutrons in the second and third leg is relatively independent of the incident source.

Also from our measurements and Fig. 3, we found that the first right angle corner reduced the flux by a factor of 5 in the second leg, and the second right angle corner reduced the flux by a factor of 4 in the third leg. Zeus's predictions state that a culdesac one unit deep reduces the flux in the following leg by a factor of 2.5 to 3.

SOURCE CALCULATIONS

Goebel et al., (Lab. II-RA/note 175-10) have estimated the neutron generations by primary protons in the hundreds of GeV energy region. If there is a sufficient amount of steel in the radial direction, they estimate 1-2 fast neutrons per GeV of the primary protons are produced with an isotropic angular distribution. Assuming 1 neutron/GeV isotropically distributed, we can estimate a rem dose at the labyrinth mouth in the following manner:

$$\text{Dose (rem)} = \frac{N * E}{4\pi r^2 F} = \frac{4.5 \times 10^{14}\ 300}{4\pi\ (6.7 \times 12 \times 2.54)^2\ 3 \times 10^7}$$

$$= .9 \times 10^4 \text{ rem}$$

N = number of incident protons = 4.5×10^{14}

E = incident energy in GeV = 300 GeV

r = source to detector distance

F = neutrons/cm^2 rem = 3×10^7

Sam Baker has estimated (using a Pu Be source as a calibration) that the neutron rem dose is 5/16 x Dose (rads) for the TLD's used in this experiment. Hence, the experimetal rem dose to the first details in the labyrinth is $5/16 \times 2.6 \times 10^4 = .8 \times 10^4$ rem. Hence, the rough estimate given by the CERN group is in good agreement with the experimental results.

CONCLUSION

From our experimental data we conclude that an exponential parameterization is better than an A/X^2 parameterization. The combination of the two is needed in the first leg to adequately reproduce all the data (the first points especially). This parameterization has physical meaning in the first leg only; however, for completeness, results are given for the other two legs. Physically, the parameterization describes the attenuation of the neutrons due to air scattering after a correction has been made for geometrical effects. Since the source calculation is adequate one could predict future results for a similar geometry using these parametric fits. Furthermore, we conclude that more general studies (different geometries) using Zeus can be made with some confidence, if one uses them to predict the neutron attenuation at the end of a multi-legged labyrinth.

ACKNOWLEDGEMENTS

The experimental work was done at the time that E-211 was running and the other members of E-211 helped in the placement and retrieval of the detectors. The TLD's were read by D. Voy and S. Baker.

Table I

Normalization of the Readings (R)

TLD No.	Distance-ℓ	$\ell/\sqrt{A}$	Reading (R)	Norm. of Reading (R)
3-016	252"	4.477	66.5	2.59×10^{-3}
3-038	540"	9.594	0.052	2.03×10^{-6}
3-040		10.874	.0123	4.80×10^{-7}
3-039	436"	7.746	1.785	6.96×10^{-5}
3-051		6.40	4.208	1.64×10^{-4}
3-046	468"	8.316	1.236	4.82×10^{-5}
3-045	504"	8.955	0.126	4.91×10^{-6}
3-018	396"	7.036	3.098	1.208×10^{-4}
3-054	252"	4.477	288.137	1.123×10^{-2}
3-052	324"	5.757	11.053	4.31×10^{-4}
3-017	0		25638.103	1
3-049	612"	8.64	0.6377	2.49×10^{-5}
3-058	648"	11.514	0.008	3.12×10^{-7}
3-057	144"	2.559	1517.47	5.92×10^{-2}
3-047			0.0	0
3-050	576"	10.235	0.025	9.75×10^{-7}
3-032			0.020	7.80×10^{-7}
3-055	216"	3.838	457.801	1.79×10^{-2}
3-031	684"	12.154	0.0088	3.43×10^{-7}
3-035	108"	1.919	2720.854	1.061×10^{-1}
3-036			33159.428	
3-042	288"	5.117	22.7	8.85×10^{-4}
3-037	180"	3.198	807.0	3.15×10^{-2}
3-041	36"	.640	10600.0	4.13×10^{-1}
3-019	72"	1.279	5360.0	2.09×10^{-1}
3-056	288"	5.117	288.0	1.123×10^{-2}
33-033	360"	9.28	.993	3.87×10^{-5}

TABLE II

Zeus's Results

ℓ	Normalization of Exposure
0	1
.55	6.2×10^{-1}
1.10	4.1×10^{-1}
1.50	3.2×10^{-1}
2.00	2.1×10^{-1}
2.60	1.7×10^{-1}
3.00	1.5×10^{-1}
4.10	1.0×10^{-1}
4.50	9.0×10^{-2}
5.35	2.45×10^{-3}
5.80	1.4×10^{-3}
6.45	8.0×10^{-4}
7.00	4.2×10^{-4}
8.00	1.7×10^{-4}
8.50	1×10^{-4}
9.00	7.0×10^{-6}
9.70	3.2×10^{-6}
10.20	1.65×10^{-6}
11.75	7.5×10^{-7}
11.2	4.8×10^{-7}
12.2	1.65×10^{-7}
13.2	5.2×10^{-8}

TABLE III

Values of the Parameters and Constants

Values of the parameters used in the exponential fit (Bie^{-CiX})

	Bi	Ci
First Leg	.745±.10	.98±.05
Second Leg	.207±.01	1.05±.001
Third Leg	.218±.02	1.20±.01

Values of the normalization constants used in the $1/X^2$ fit (Ai/X^2)

	Ai
First Leg	.29±.01
Second Leg	.00062±.00004
Third Leg	.0000022±.0000002

Values of the slope parameters in the $De^{-Fx}/(1+x)^2$ fit

	Fi	1
First Leg	.37±.01	1.43
Second Leg	.11±.006	.32
Third Leg	.11±.002	.32

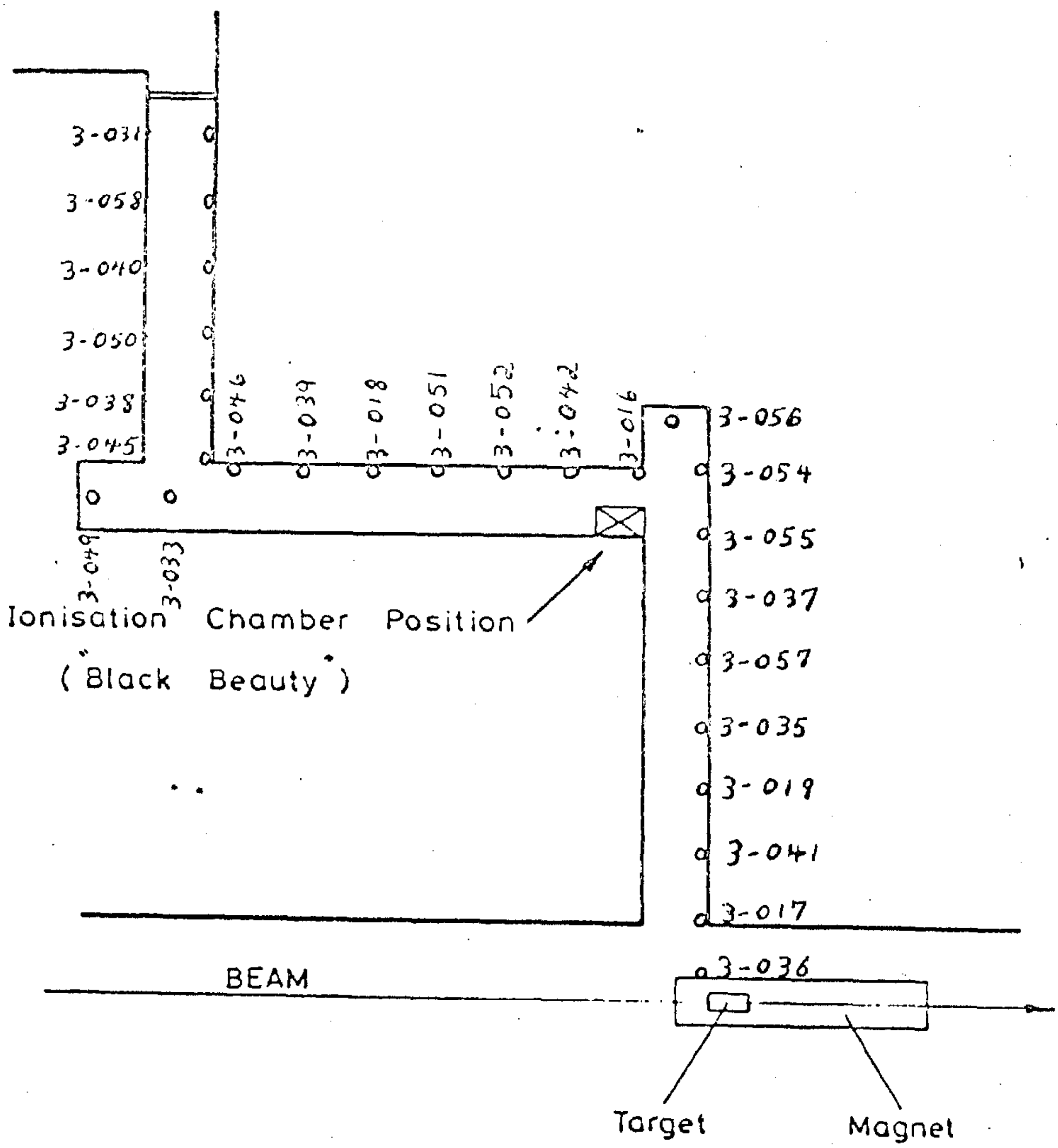

Fig. 1 Ionisation Chamber Position in the access Labyrinth of the Neutrino Hall

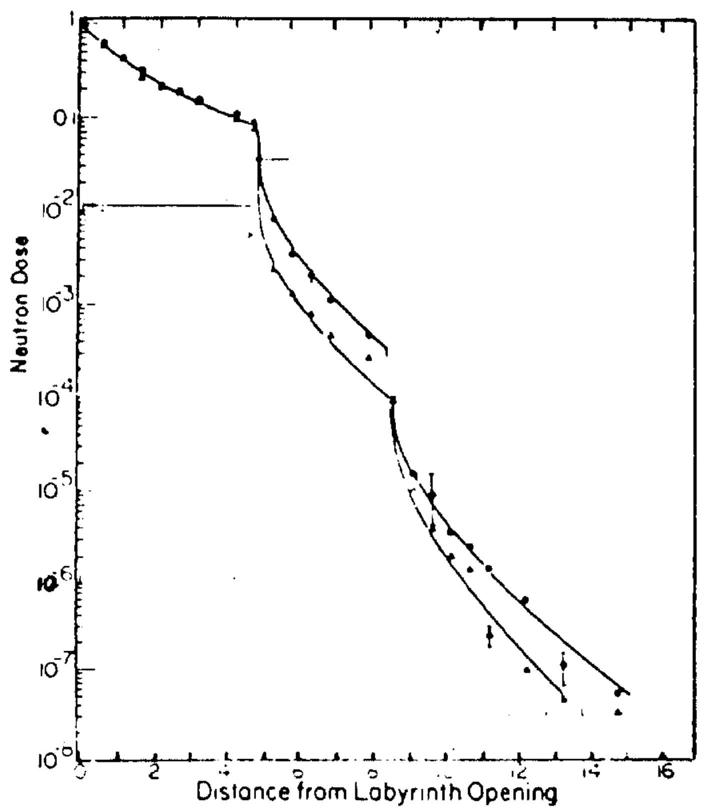

Fig. 2 Neutron dose of Zeus calculations constructed from two of Zeus's figures by proper terminations and connections.

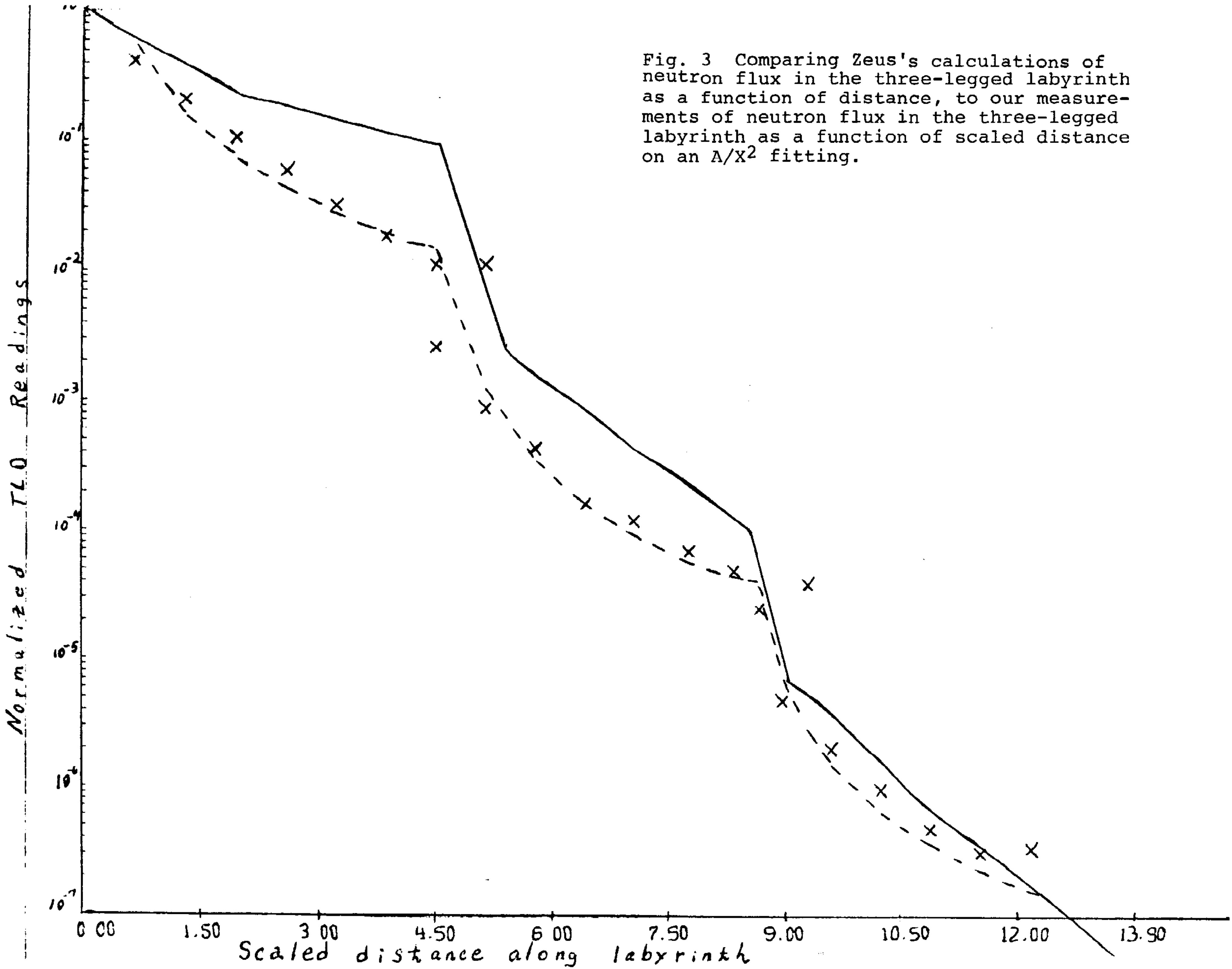

Fig. 3 Comparing Zeus's calculations of neutron flux in the three-legged labyrinth as a function of distance, to our measurements of neutron flux in the three-legged labyrinth as a function of scaled distance on an A/X^2 fitting.

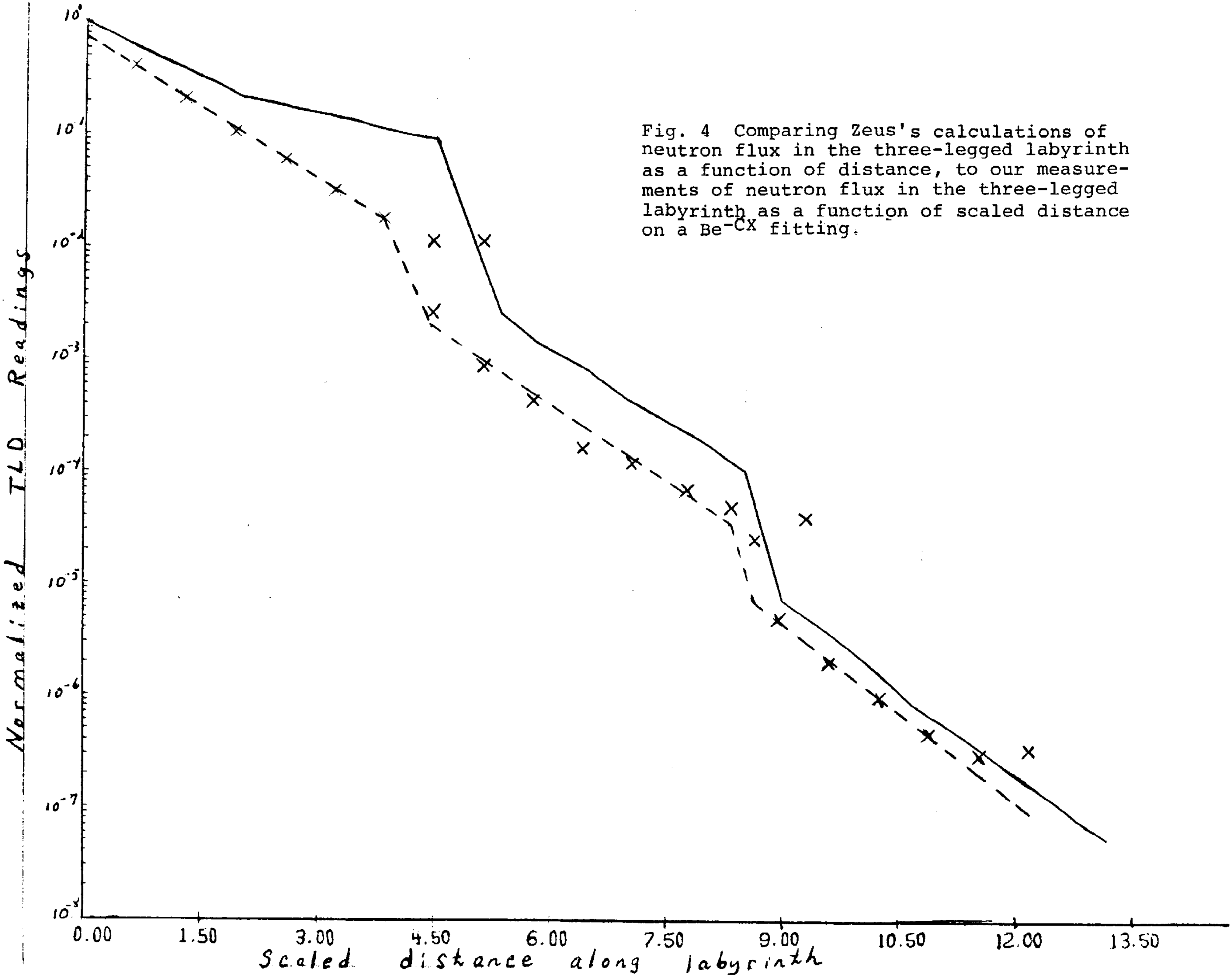

Fig. 4 Comparing Zeus's calculations of neutron flux in the three-legged labyrinth as a function of distance, to our measurements of neutron flux in the three-legged labyrinth as a function of scaled distance on a Be^{-Cx} fitting.

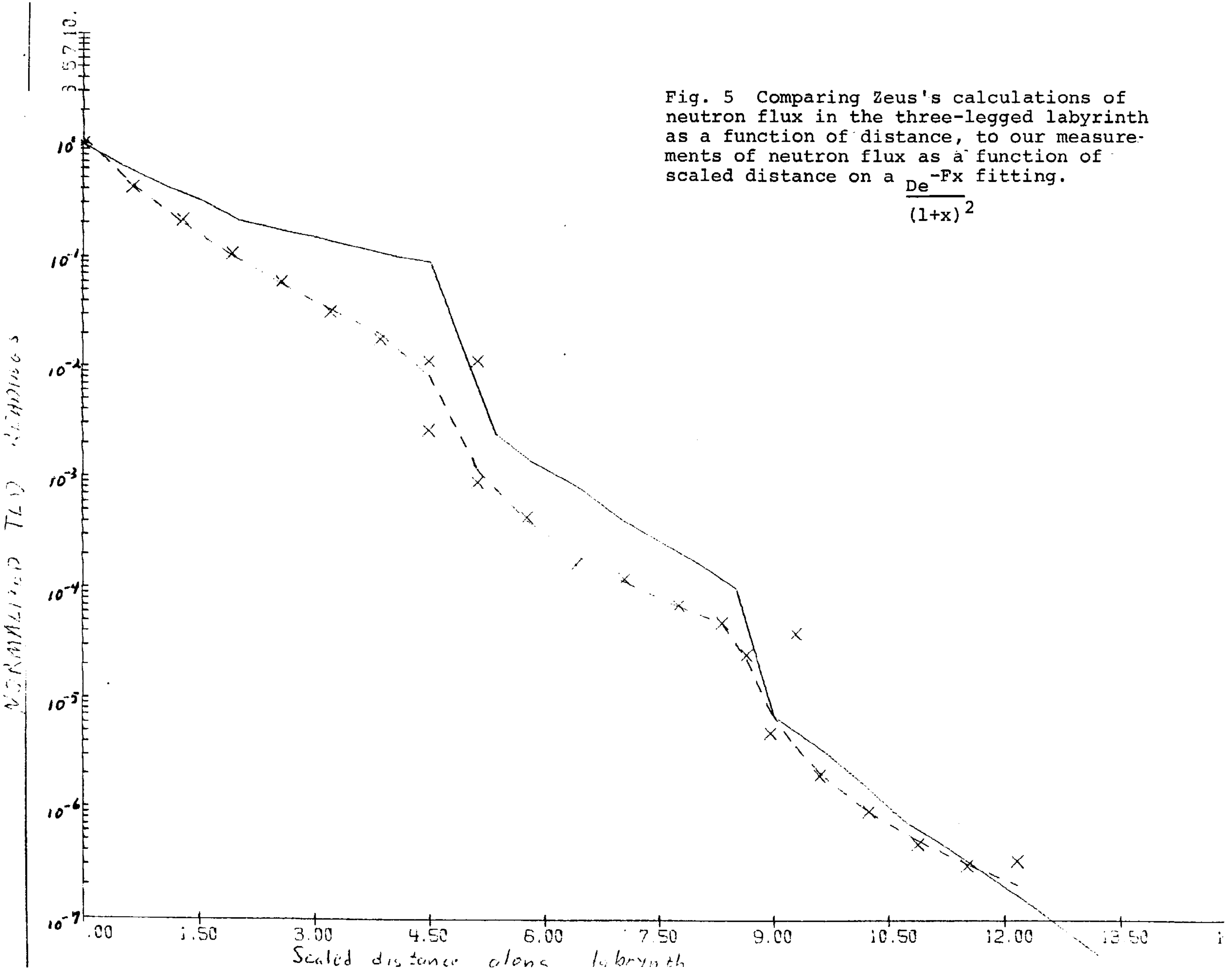

Fig. 5 Comparing Zeus's calculations of neutron flux in the three-legged labyrinth as a function of distance, to our measurements of neutron flux as a function of scaled distance on a $\frac{De^{-Fx}}{(1+x)^2}$ fitting.